RFA # EPA-OAR-OAQPS-21-03
Attachment 6-B
Development, Demonstration and Certification of 15-Liter Natural Gas Engine Project
Emissions Reduction Calculation Attachment

The 15-liter project is poised to deliver substantial emission reduction benefits through the deployment of 10 pre-commercial demonstration trucks and as well as the sales of the new 15-liter natural gas engine once it's available for commercial deployment by end of 2023. Both EPA's DEQ and CARB's Carl Moyer Calculator were evaluated, South Coast AQMD staff ultimately went with Carl Moyer Calculator as it already has emissions factors and deterioration factors for lower NOx technologies in this project. The emissions reduction calculation is based on the Carl Moyer methodology presented in this document in appendix.

Table D-2
Heavy-Duty Vehicles Over 33,000 pounds (lbs) GVWR
Emission Factors (g/mile)[(a)] (EF) and Deterioration Rates (g/mile-10k miles) (DR)

Engine Model Year	NOx[(b)] EF[(d)]	NOx[(b)] DR[(e)]	ROG[(b),(c)] EF[(d)]	ROG[(b),(c)] DR[(e)]	PM[(b),(i)] EF[(d)]	PM[(b),(i)] DR[(e)]
Pre-1987	21.37	0.018	1.38	0.031	1.26	0.02
1987-90	21.07	0.024	1.08	0.037	1.369	0.0178
1991-93	18.24	0.037	0.78	0.027	0.574	0.0104
1994-97	17.92	0.043	0.58	0.031	0.377	0.008
1998-02	17.61	0.049	0.6	0.031	0.415	0.0073
2003-06	11.66	0.049	0.49	0.018	0.267	0.0041
2007-09	6.8	0.077	0.39	0.007	0.022	0.0006
2007+[(f)] (0.21-0.50 g/bhp-hr NOx FEL)	2.17	0.068	0.13	0.002	0.004	0.0001
2010-12 (0. 2 g/bhp-hr NOx std)	1.76	0.068	0.13	0.002	0.004	0.0001
2013+[(g)] (0. 2 g/bhp-hr NOx std)	1.76	0.039	0.13	0.001	0.004	0.0001
2016+[(h)] (0.10 g/bhp-hr NOx std)	0.88	0.019	0.13	0.001	0.004	0.0001
2016+[(h)] (0.05 g/bhp-hr NOx std)	0.44	0.01	0.13	0.001	0.004	0.0001
2016+[(h)] (0.02 g/bhp-hr NOx std)	0.18	0.004	0.13	0.001	0.004	0.0001

Figure 1 CARB Carl Moyer Emission Factors for Heavy-Duty Trucks.

As noted above, Carl Moyer does not consider ROG and PM benefit for 0.05 and 0.02 technologies. Thus, only NOx reduction is considered for this study. Further, instead of estimating diesel fuel burned (Table 8 below), as CARB's Low Carbon Fuel Standard (LCFS) highlights of the uses of RNG, South Coast AQMD staff calculates GHG emission reduction estimates in place of diesel fuels burned. Two cases are presented, fossil and biomethane CNG with carbon intensity presented in CARB ZANZEFF attachment. Further GHG reduction calculation methodology was based on what's presented in CARB ZANZEFF Appendix D. Both documents were accessed via pdfs posted on CARB's website.

Table 1 below show key assumptions and inputs for calculation. Since this study plans to deploy the 15-liter trucks to wide variety of customers with different application, A very modest estimate of annual VMT of 50,000 miles, and 7 mile per gallon diesel truck efficiency was assumed which are more typical for short-haul and drayage applications, therefore, the emissions reduction estimate is rather modest. For more flexibility, South Coast staff calculated the NOx Deterioration Product for 0.2, 0.05, and 0.02 technologies from Formula C-4 in Carl Moyer Program Guidelines. This is an combination of the project life, VMT, and Deterioration Factor provided in Figure 1 above, the Deterioration Product is in grams of NOx per mile and it's directly added to the emission factor and multiplied by VMT to get the annual NOX emitted, an example for 0.2 gram is shown below.

$$Deterioration\ Product = Deterioration\ Rate * Annual\ VMT * Deterioration\ Life$$
$$= \left(\frac{0.039\ grams}{mile}\right) * \left(\frac{1}{10{,}000\ miles}\right) * 50{,}000\ miles * \left(\frac{10\ years}{2}\right) = \frac{0.975\ grams}{mile}$$

Table 1 Assumptions and Inputs for NOx, GHG Emissions Reductions Calculations.

Factor	Unit	Description	Source
50,000	miles/trucks/year		
7	miles/gal		
10	years	project life	
102.01	g CO2e/MJ	CI Diesel	ZANZEFF, page D-57
78.37	g CO2e/MJ	CI Fossil CNG	ZANZEFF, page D-57
46.42	g CO2e/MJ	CI Fossil Biomethane CNG	ZANZEFF, page D-57
134.47	MJ/gal	ED diesel	ZANZEFF, page D-56
1.04	MJ/SCF	ED CNG	ZANZEFF, page D-56
0.9		EER CNG	ZANZEFF, page D-58
1.76	g NOx /mile	0.2 Baseline	Table D-2, CM Efs
0.44	g NOx /mile	0.05 NOx EF	Table D-2, CM Efs
0.18	g NOx /mile	0.02 NOx EF	Table D-2, CM Efs
0.039	g/mike - 10 k miles	DF for 0.2	Table D-2, CM Efs
0.01	g/mike - 10 k miles	DF for 0.05	Table D-2, CM Efs
0.004	g/mike - 10 k miles	DF for 0.02	Table D-2, CM Efs
0.975	g NOx /mile	Deterioration Product for 0.2	Formula C-4, CM Program Guidelines
0.250	g NOx /mile	Deterioration Product for 0.05	Formula C-4, CM Program Guidelines
0.100	g NOx /mile	Deterioration Product for 0.02	Formula C-4, CM Program Guidelines
907200	g/ton	Conversion ratio	ZANZEFF, page D-23
0.508	CRF for 2 yr project life		ZANZEFF, page D-82
0.106	CRF for 10 yr project life		ZANZEFF, page D-82

Based on inputs in Table 1, per truck NOx and GHG emissions associated with each technology can be calculated by either multiple by VMT or by fuel burned. An example for NOx and GHG is shown below, detailed results are in Table 2 using the same methodology.

$$Fuel\ Usage_{baseline} = \frac{gal\ diesel}{year} = \left(\frac{1\ gallon}{7\ miles}\right) * \left(\frac{50{,}000\ miles}{1\ year}\right) = \frac{7{,}143\ gallons\ diesel}{year}$$

$$Fuel\ Usage_{CNG} = \left(\frac{7{,}143\ gal\ diesel}{year}\right) * \left(\frac{134.47\ MJ}{gal\ diesel}\right) * \left(\frac{1\ SCF}{1.04\ MJ}\right) * \left(\frac{1}{0.9}\right) = 1{,}026{,}175\ \frac{SCF}{year}$$

$$GHG\ EF_{baseline} = \left(\frac{102.01\ gCO2e}{MJ}\right) * \left(\frac{134.47\ MJ}{gal}\right) * \left(\frac{7{,}143\ gal}{year}\right) * \left(\frac{1\ MT\ CO2e}{1e6\ grams}\right) = 97.98\frac{MT\ CO2e}{year}$$

$$GHG\ EF_{Fossil\ CNG} = \left(\frac{78.37\ gCO2e}{MJ}\right) * \left(\frac{1.04\ MJ}{SCF}\right) * \left(\frac{1{,}026{,}175\ scf}{year}\right) * \left(\frac{1\ MT\ CO2e}{1e6\ grams}\right) = 83.64\frac{MT\ CO2e}{year}$$

$$Project\ GHG\ ER_{annual} = \left(\frac{97.98\ MT\ CO2e}{year}\right) - \left(\frac{83.64\ MT\ CO2e}{year}\right) = 14.34\ \frac{MT\ CO2e}{year}$$

$$Annual\ ER_{NOx,0.2} = (\left(\frac{1.76\ g\ NOx}{mile}\right) * \left(\frac{50{,}000\ miles}{year}\right) + \left(\frac{0.975\ g\ NOx}{mile}\right) * \left(\frac{50{,}000\ miles}{year}\right)) * \left(\frac{1\ ton}{907{,}200\ g}\right) = 0.151\frac{tons\ NOx}{year}$$

$$Annual\ ER_{NOx,0.02} = (\left(\frac{0.18\ g\ NOx}{mile}\right) * \left(\frac{50{,}000\ miles}{year}\right) + \left(\frac{0.004\ g\ NOx}{mile}\right) * \left(\frac{50{,}000\ miles}{year}\right)) * \left(\frac{1\ ton}{907{,}200\ g}\right) = 0.015\frac{tons\ NOx}{year}$$

$$Project\ NOx\ Reduction\ 0.2\ to\ 0.02\ _{annual} = \left(\frac{0.151\ tons\ NOx}{year}\right) - \left(\frac{0.015\ tons\ NOx}{year}\right) = 0.135\ \frac{tons\ NOx}{year}$$

Table 2 Per-truck annual NOx and GHG Emissions Reductions Results

GHG Reductions per truck per year		
7,143	gal diesel/year	baseline annual fuel use
1,026,175	scf/year	equivalent CNG scf
97.98	MT CO2e/year	GHG EF base
83.64	MT CO2e/year	GHG EF fossil CNG
49.54	MT CO2e/year	GHG EF biomethane CNG
14.34	**MT CO2e/year**	**Project GHG ER annual fossil CNG**
48.44	**MT CO2e/year**	**Project GHG ER annual biomethane CNG**
Criteria Pollutant Reductions per truck per year		
0.151	tons NOx/year	NOx emissions base
0.038	tons NOx/year	NOx emissions 0.05
0.015	tons NOx/year	NOx emissions 0.02
0.135	**tons NOx/year**	**NOx reduced base to 0.02**
0.023	**tons NOx/year**	**NOx reduced 0.05 to 0.02**

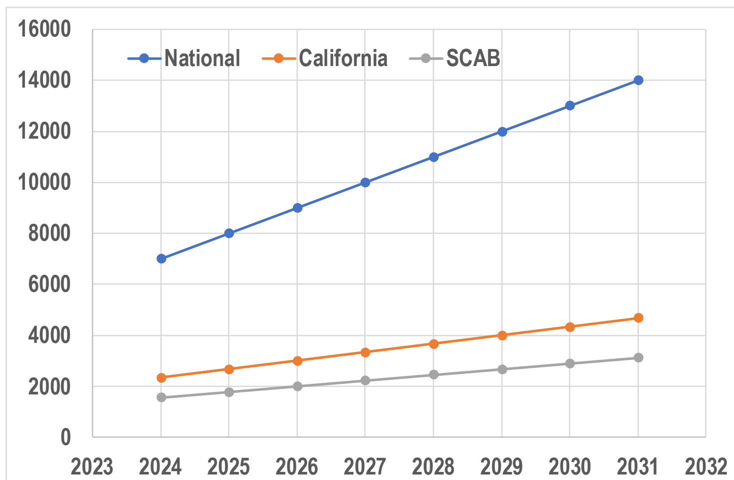

Figure 2 Projected 15-liter Sales through 2031.

In order to estimated boarder project benefit, a reasonable estimate for number of trucks deployed once the 15-liter is ready for commercial sale is needed for SCAB area. As allowed in the RFA, demonstration project such as this one can estimate future emission reductions of wider deployment after project completion. Thus, for calculation of the emissions benefits beyond the project period, Cummins has provided sales projection of the new 15-liter sales for National, California, and SCAB, see Figure 2. Cummins stated these estimates are modest as typical year U.S. Class 8 tractor sales is ~250,000 units with 100,000 day cab tractors operating in urban return to base operations and 150,000 sleeper cab tractors for long-haul operation (Figure 3). Class 8 day cab sales volume are consistent each year and operated by same owner by 8-12 years whereas class 8 sleeper cab trucks are traded out of service by first owner every 4-5 years. This is also preferred vehicle and configuration for owner/operators that can serves wide variety of application including drayage operations and procure newer trucks at a lower price point. Adding the 15-liter natural gas engine to Cummins product offerings will give carriers from a much larger market segment to transition from the incumbent engine technology to natural gas engines without compromising on performance, durability, reliability, or efficiency. Cummins believe the increased awareness on fleet sustainability goals and regulatory compliance will even broaden low-NOx natural gas trucks running on RNG to more fleets. The added the benefit of transforming of the owner-operator vehicle segment to lower emission vehicle through secondary market is another important consideration for this project. For those reasons, the sales estimates in this project is reasonable and justified.

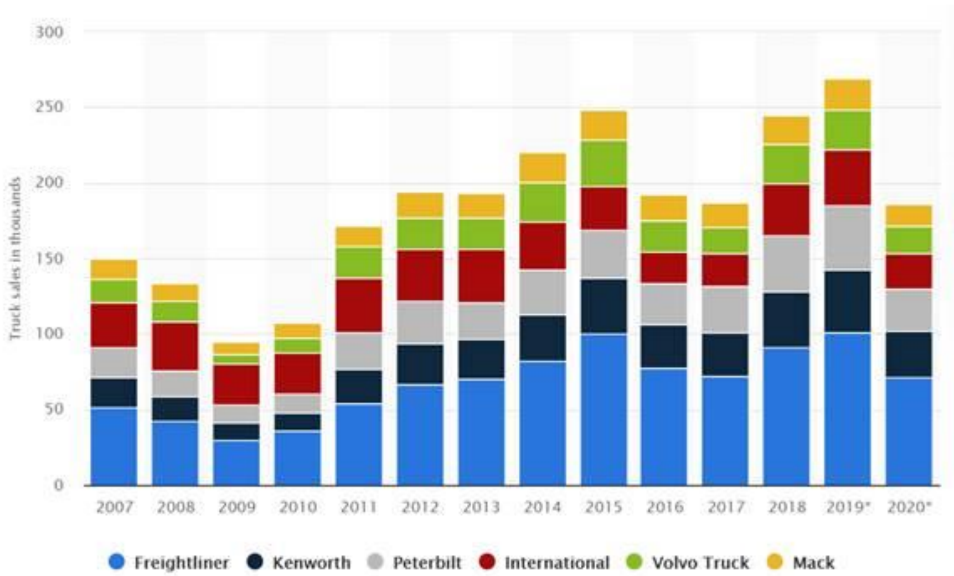

Figure 3. U.S. Class 8 Truck sales by OEM, courtesy of Cummins Inc.

These estimated sales volumes were added on top of the 10 demonstration trucks deploying starting 2022 which are expected to remain with customer after project end. For simplicity, the emissions reduction is only calculated for 10 years between 2022 and 2031,regardless of when the estimated truck sales occurs, but the trucks deployed in later years are expected to remain in service for its full useful life and continue to provide emissions reductions for SCAB and beyond. For the same reason, the annualized emissions reductions are all averaged over 10 years from the lifetime totals between 2022 and 2031. Table 3 sums up the annual and lifetime emissions reduction for this project. Detailed year over year results are presented in Tables 4-7.

Table 3 Anticipated Outputs and Outcomes for averaged Annual and Lifetime through between 2022 and 2031.

Outputs	Outcomes			
Emissions/Diesel Fuel Reductions (tons/gallons)		**NOx (tons)**	**GHG (MT CO2e for fossil CNG)**	**GHG (MT CO2e for biomethane CNG**
Repower 10 0.2 diesel fueled 0.2 Class 8 trucks with 0.02 NG engine	Annual*	1.35	143	484
	Lifetime	13.53	1,434	4,844
Deploy 5,334 new 0.02 NG Class 8 trucks in-lieu of 0.05 diesel trucks (2024-2026)	Annual*	83.37	52,915	178,715
	Lifetime	833.69	529,148	1,781,151
Deploy 13,337 new 0.02 NG Class 8 trucks in-lieu of 0.02 diesel trucks (2027-2031)	Annual*	0	54,197	183,046
	Lifetime	0	541,971	1,830,456
Total	Annual*	84.72	107,255	362,245
	Lifetime	847.22	1,072,553	3,622,451
Cost-effectiveness (per ton/MT reduced), total project cost	$18,907,000	$22,316.40	$17.63	$5.22
Cost-effectiveness (per ton/MT reduced), total EPA ask	$8,000,000	$9,442.60	$7.46	$2.21

*Due to different deployment years, all annual reductions are lifetime reductions averaged over 10 years

Additional emission reduction is likely to occur since long-haul trucks that travels beyond SCAB, and natural gas truck are also popular in other areas of U.S., as show below in Figure 4. The full commercial roll out of the 15-liter natural gas engine will benefit other non-attainment areas in California and other areas of US.

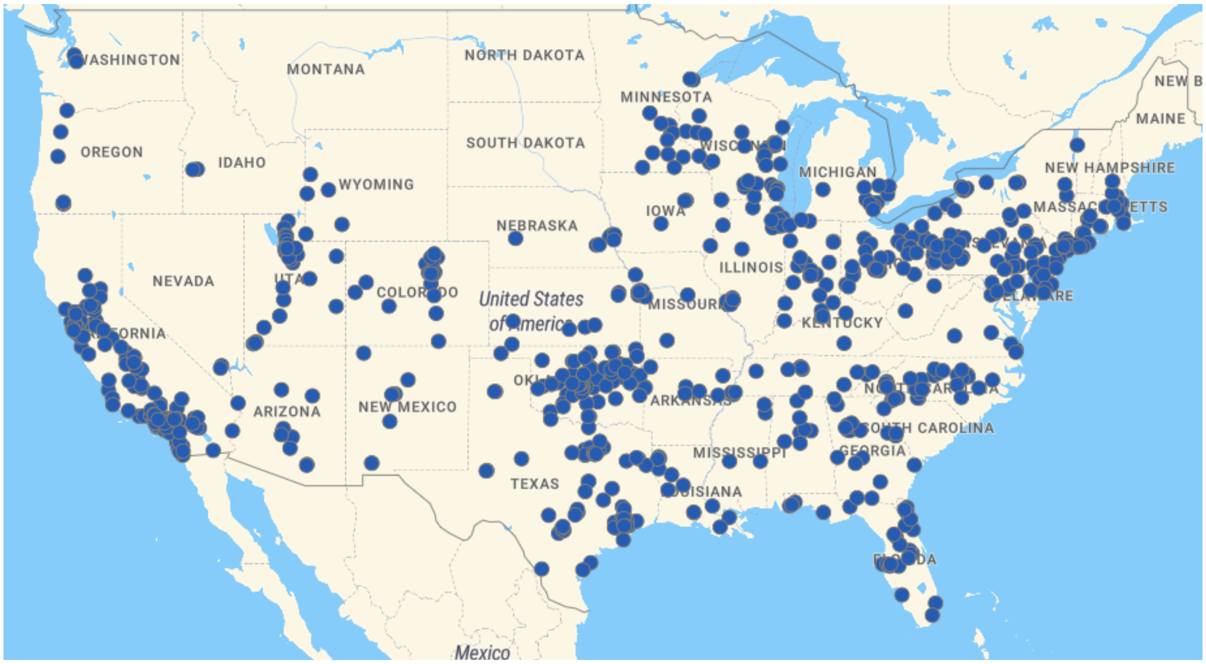

Figure 4 Public CNG refueling station within the U.S., from DoE Alternative Fuel Data Center

Using the same calculation methodology and sales estimates provide in Figure 2, emission reduction benefit for California and entire U.S. are presented in Table 4 below. Multiple fleets committed in the demonstration program has expressed interest in using the 15-liter demonstration trucks for long-haul service to their operation in North California, Arizona, Nevada, even Texas.

Table 4. Averaged Annual and Lifetime Emissions Reduction through between 2022 and 2031 for California and U.S.

	NOx (tons per year)	GHG MT CO2e, Fossil CNG	GHG MT CO2e, Biomethane CNG
Reduction for California (10 demo + 28,000 trucks between 2024 and 2031)			
Annual (average)	126.41	160,798	543,082
Lifetime (2022-2031)	1264.07	1,607,984	5,430,819
Reductions for U.S. (10 demo + 84,000 trucks between 2024 and 2031)			
Annual (average)	376.46	482,048	1,628,073
Lifetime (2022-2031)	3,764.63	4,820,480	16,280,734

Appendix: Detailed year over year calculation results for SCAB.

Tables 5-8 Detailed year over year calculation results for NOx, GHG, Diesel Fuel for SCAB.

Table 5 NOx

	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
10 demo trucks	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
MY 2024 Sales			35.16	35.16	35.16	35.16	35.16	35.16	35.16	35.16
2025 Sales				40.18	40.18	40.18	40.18	40.18	40.18	40.18
2026 Sales					45.19	45.19	45.19	45.19	45.19	45.19
2027 Sales										
2028 Sales										
2029 Sales										
2030 Sales										
2031 Sales										
Total NOx										847.22

Per year										84.72
Table 6 GHG Fossil										
	2022	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**
10 demo trucks	143	143	143	143	143	143	143	143	143	143
MY 2024 Sales			22,317	22,317	22,317	22,317	22,317	22,317	22,317	22,317
2025 Sales				25,501	25,501	25,501	25,501	25,501	25,501	25,501
2026 Sales					28,685	28,685	28,685	28,685	28,685	28,685
2027 Sales						31,883	31,883	31,883	31,883	31,883
2028 Sales							35,067	35,067	35,067	35,067
2029 Sales								38,251	38,251	38,251
2030 Sales									41,450	41,450
2031 Sales										44,634
Total GHG										1,072,553
Per year										107,255
Table 7 GHG Biomethane CNG										
	2022	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**
10 demo trucks	484	484	484	484	484	484	484	484	484	484
MY 2024 Sales			75,373	75,373	75,373	75,373	75,373	75,373	75,373	75,373
2025 Sales				86,127	86,127	86,127	86,127	86,127	86,127	86,127
2026 Sales					96,880	96,880	96,880	96,880	96,880	96,880
2027 Sales						107,682	107,682	107,682	107,682	107,682
2028 Sales							118,436	118,436	118,436	118,436
2029 Sales								129,190	129,190	129,190
2030 Sales									139,992	139,992
2031 Sales										150,746
Total GHG										3,622,451
Per year										362,245
Table 8 Diesel										
	2022	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**
10 demo trucks	71,429	71,429	71,429	71,429	71,429	71,429	71,429	71,429	71,429	71,429
MY 2024 Sales			11,114,286	11,114,286	11,114,286	11,114,286	11,114,286	11,114,286	11,114,286	11,114,286

2025 Sales				12,700,000	12,700,000	12,700,000	12,700,000	12,700,000	12,700,000	12,700,000
2026 Sales					14,285,714	14,285,714	14,285,714	14,285,714	14,285,714	14,285,714
2027 Sales						15,878,571	15,878,571	15,878,571	15,878,571	15,878,571
2028 Sales							17,464,286	17,464,286	17,464,286	17,464,286
2029 Sales								19,050,000	19,050,000	19,050,000
2030 Sales									20,642,857	20,642,857
2031 Sales										22,228,571
Total Diesel										534,157,143
Per year										53,415,714